FOSSIL FREIGHT: HOW MUCH FOSSIL FUEL DOES IT TAKE TO MOVE FOSSIL FUEL?

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This paper asks as the question: how much fossil fuel does it take to move fossil fuel inside the U.S.? An understanding of this "fossil freight", which takes up a significant portion of U.S. freight's capacity, can support new policies or business innovations to halt and reverse the trend of rising energy use in the freight sector. In addition, it can support a more comprehensive view of the impact of fossil fuel use on the environment and economy. In 1970, freight contributed ~4% of U.S. CO₂-eq emissions; by 2007, that figure had risen to nearly 8%. Furthermore, the carbon intensity of freight movement, as measured in CO₂-eq per ton-mile is still rising, whereas the intensity of passenger travel per person-mile is falling. For freight, this can be largely attributed to a shift in modes: moving to more truck and air freight from rail and barge freight. Previous findings point out the importance of more investigation into the drivers behind the increasing freight emissions, and intensity. This paper tackles one major category of goods that utilize all freight modes, (including pipelines, which are often left out of freight calculations and policy): fossil fuels. The fuel used to move other fuels is called “fossil freight.” In 2007, one fifth of freight’s energy use went towards the transport of oil, coal, and natural gas products (down from 30% in 1970). Fossil freight absolute energy has remained relatively constant in the U.S. since 1970, due to a variety of balancing forces: whereas fossil fuel use has more than doubled, average trip length for oil and the energy intensity of key modes (such as oil pipelines) has decreased. The decrease in oil trip length, a key driver, coincides with the increase of oil imports, indicating the importance of consideration of the impact that fuel destined for the U.S. has before it reaches U.S. borders.

Fossil freight was responsible for 100% of pipeline tonne-km, 40% of freight rail tonne-km, and 15% of domestic waterborne tonne-km in 2007. These modes are an order of magnitude (or more) less energy intensive than trucking, and several orders more efficient than air freight. As the nation reduces fossil fuel use and frees up this efficient freight infrastructure, leaders must construct policies and plan infrastructure to utilize this capacity for non-fossil freight, and, in doing so, tackle the ever-increasing intensity and greenhouse gas emissions from the freight industry.
INTRODUCTION: EVOLUTION OF CARBON EMISSIONS FROM THE FREIGHT SECTOR

This paper asks the question: how much fossil fuel does it take to move fossil fuel inside the U.S.? An understanding of this "fossil freight", which takes up a significant portion of U.S. freight's capacity, can support new policies or business innovations to halt and reverse the trend of rising energy use in the freight sector. In addition, understanding fossil freight can lead to a better understanding of the full cost of fossil fuel reliance, and help create the foundation for models to analyze how a move away from fossil fuels would affect U.S. freight industry.

Transportation in the U.S. accounted nearly 2000 million metric tonnes (CO₂ equivalent) of greenhouse gas emissions in 2007, and the rate of increase in emissions from transportation emissions is rising faster than the rate of total emissions. While much attention from the policy and academic communities have been directed towards consideration of how to reduce this figure, the majority of these discussions have focused on the movement of people (for example Morrow et. al. 2009). However, as pointed out in Schipper and Sudarshan, freight has come to play an increasingly large role in U.S. transportation emissions and energy use (see Figure 1). The US is not alone in this phenomenon: interest in Europe and other OECD countries is also turning towards the rising impact of freight. In 1970, freight contributed ~4% of U.S. CO₂-eq emissions; by 2007, that figure had risen to nearly 8%. Furthermore, the carbon intensity of freight movement, as measured in CO₂-eq per ton-mile is falling. For freight, this can be largely attributed to a shift in modes: moving to more truck and air freight from rail and barge freight. Often, oil and natural gas pipelines are left out of freight calculations (such as in the 2010 paper cited above), and adding them will exacerbate calculation of rising impact of freight.

These previous findings point out the importance of more investigation into the drivers behind the increasing freight emissions, and intensity. This paper tackles one major category of freighted goods: fossil fuels. In this paper, the transportation of fossil fuels is called “fossil freight.” In 2007, one quarter of freight’s energy use went towards the transport of oil, coal, and natural gas products. These figures exclude the losses incurred “freighting” of electrons over transmission and distribution wires, which accounted for 6.5% of generated electricity in 2007 and substituted in part for bulky fossil fuels that provided space and water heating, as well as process energy and traction now supplied by electricity to rail and trolley systems. About 70% of electricity was generated in 2007 from fossil fuels; therefore, the losses incurred in transmission and distribution of fossil-generated electrons was 700 billion mega joules.

This share of fossil freight energy is so large that changes in fossil fuel use patterns could have a significant impact on total freight haulage and the industry’s structure. If fossil fuels were replaced by biofuels, the share of energy in freight could remain high, especially if it exacerbated the current freight modal shift to trucks. If more of the present use of fossil fuel was replaced by electricity, with its inherent losses in transmission, different changes in the “freight bill” would emerge. If lower carbon emissions were ushered in primarily by lower-than-otherwise fuel use (efficiency), then the national freight haulage and its fuel use would be lower than otherwise.

Figure 1: Index of Energy Use in U.S., Transportation, Freight, and Fossil Freight. 1970 = 100%. While freight energy has increased at a higher rate than total energy and transportation energy as whole, fossil freight energy has remained relatively constant.
As shown in Figure 1, the energy use for fossil freight has remained relatively constant. The results section of this paper will explore the drivers behind this statistic, specifically how tonnage has increased, while mileage has decreased. Figure 2 shows total freight tonne-km, broken into mode (color) and fossil-freight versus non fossil freight (shading). Since 1970, trucking (blue) has come to play a large role in freight, driving up industry energy intensity and greenhouse gas emission. While trucking attributed to fossil fuels remains low relative to other trucking—dominated by the last-mile delivery of gasoline to gas stations—a continuation of this trend could rapidly drive up fossil freight emissions, as trucking is orders of magnitudes more energy and greenhouse gas intensive than some of the other fossil freight modes and therefore has an impact on these impacts compared to its tonne-mileage (see Figures 3 and 4). Fossil freight (almost entirely coal) has been eating up rail capacity compared to non-coal shipments since 1970. While waterborne shipments for all forms of freights has diminished.

Figure 2: Fossil freight contribution to all freight tonne-km, 1970, 1990, 2007.
Figure 3: Fossil freight contribution to freight energy, 1970, 1990, 2007

Figure 4: Fossil freight contribution to freight CO₂-eq emissions from freight by mode, 1970, 1990, 2007.
FOSSIL FREIGHT: DEFINITION

“Fossil freight” refers to the fuel used to transport fossil fuels. The transportation of fossil fuels contributes over 30% of domestic freight tonne-km. These “upstream” emissions associated with using fossil fuels are usually seen as a small addition to the life cycle assessment of any product that uses fossil fuels, such as a vehicle. This paper attempts to aggregate all energy use and emissions associated with the transportation of fossil fuels within the United States, and to determine any historical drivers behind changes in these emissions. Fossil freight energy has remained relatively constant in the U.S. since 1970, due to a variety of balancing forces: whereas fossil fuel use has more than doubled, average trip length and the energy intensity of key modes (such as oil pipelines) has decrease. Emissions from fossil freight have decreased as a result of the greening of the electrical grid and reduction in leakage from natural gas pipelines in addition to the factors influencing energy.

As shown in Figure 5, total energy use in the U.S. has grown since 1970, as has total freight energy (solid lines, axis on right). The percent of total energy use attributed to fossil freight has decreased slightly, and the percent of fossil freight as a contributor towards total freight has decreased significantly (dotted lines, axis on left). This, as indicated in Figure 3, can be attributed to the rise of trucking in non-fossil freight since 1970.
Figure 5: Total U.S. energy use (orange, solid) and freight energy use (blue, solid) as well as domestic fossil freight as a percent of each from 1970-2007 (dotted). Fossil freight’s percent of freight energy has decreased as non-fossil freight moved to energy-intensive trucking mode. Fossil freight’s contribution as a percent of total energy has remained relatively constant between 1.5 and 2.5%. Note: fossil freight only includes movement within the U.S.; much fossil freight energy use is “exported” in the movement of fossil fuels through, for example, Canadian pipelines and overseas oil tankers.

APPROACH
Fossil fuels include petroleum, natural gas, and coal. The approach taken here is bottom up: the researchers scanned data going back to 1970 (where available) to find indicators of fossil fuel use and transportation to build the data set of energy use, tonne-miles, and tonnes for each fossil fuel. For each fuel the procedures were somewhat different, as outlined below:

Oil: For ton-miles of oil pipeline freight back to 1980, the Bureau of Transportation Statistics’ Improved Ton-Miles Estimates were used. For ton-mile movements prior to 1980, the 1980 data point was scaled relative to total oil and usage. For all oil movements and tonnage not in pipelines, the Department of Transportation’s Commodity Flow Survey (CFS) and its predecessors were used. These data were collected only every five years (and not during 1987 or 1982). Linear growth was assumed between each data point available from the CFS. The value for energy intensity of oil pipelines through 1982 was taken from a 1982 study by the Congressional Budget Office (0.36 MJ/tonne-km), and after 1982 a
value was used from the Trans-Alaska Pipeline Survey Environmental Impact Report (0.22 MJ/tonne-km).\textsuperscript{14} Energy intensity for other modes was taken from the Transportation Energy Data Book (*henceforth TEDB)\textsuperscript{15} and the National Transport Statistics.\textsuperscript{16} The share of light trucks not used as personal vehicles, as well as proportional shares of light truck VKT and fuel use were taken from the TEDB, based in turn on TIUS and VIUS (Schipper and Sudarshan 2010). Light trucks were assumed to carry 200 kg of freight, and medium trucks (single body) 3 metric tonnes to add their freight haulage to that of interstate trucking noted in TEDB. Tonnage of oil in pipelines was taken from the Bureau of Transportation Statistics, and only reported every 10 years between 1960 and 1990 (and not at all after 2001).\textsuperscript{17} For missing data points, the tonnage was estimated to grow linearly between known data points. For dates after 2001, tonnage was assumed to grow at the same rate as ton-miles. Distance data was not explicitly available for any mode for oil; however, average trip distance by mode could be ascertained by dividing ton-mile data by tonnage.

\textbf{Natural gas:} All natural gas movement was assumed to occur in pipelines; most CFS data sets combine liquefied natural gas (LNG) moved in trucks with “other petroleum products,” and LNG tonnage is very small compared to total petroleum movements, and so these movements were bundled with the oil movements (The BTS estimated total ton-miles for natural in pipelines from 1980.\textsuperscript{18} This estimate was made by taking the total tonnage of natural gas in pipelines, and applying the average trip length of oil in oil pipelines, a method which, as we explain below, may have underestimated the total ton-miles. The total energy used in pipelines, storage and transmission is available from the Energy Information Administration’s Annual Energy Review (AER).\textsuperscript{19} Therefore, for natural gas this direct energy use figure was used, instead of multiplying energy intensity per tonne-km by tonne-km to get total energy use (as done for oil and coal).

Estimates of energy intensity of natural gas pipelines were available from Argonne National Labs. This figure, around 300 btu/tonne-km, was a factor of four times as small as the btu/tonne-km that would be derived by dividing the EIA’s total energy use in pipelines by the BTS’ estimate of tonne-km.\textsuperscript{20} This indicates that either the tonne-km estimate used by the BTS is low, or that much energy is used in storage inside pipelines.

To calculate the greenhouse gas impact of pipelines, leakages must also be taken into account. This data was taken from the EIA’s inventory of greenhouse gases, from the natural gas transmission, storage, and distribution categories.\textsuperscript{21} Data was only available back to 1990. For dates previous to 1990, the leakages were indexed to the change in total natural gas tonne-miles between 1990 and the target year.

\textbf{Coal:} Coal movements proved challenging to document. The Energy Information Administration (EIA)’s Coal Transportation Rate Database (CTRDB) provides detailed records, including tonnage and distance by mode from 1979 to 2001. However, the database only captures a portion of all coal shipments. The EIA’s Coal Distribution report compilation covers all shipments of coal by tonnage and mode from 1994 through 2008, but does not give distance. It does, however, give origin and destination states. Therefore, the average distance between each pair of states by mode was calculated from the CTRDB data and these averages were applied to the data included in the CD set to estimate the ton-miles travelled by coal from 1994-2008. For data before 1994, tonnage was taken from the EIA’s Annual Energy Review.\textsuperscript{22} The percent of the total shipments ascribed to each mode of travel were matched to the percent of shipments on each mode of transport (by weight) from the CTRDB, and the average trip length for that year per
mode was applied to the new estimate of tonnage for each mode. All years before 1970 were fixed to 1979 percentages.

**Intensity**: Next, the energy intensity, as measured in MJ per tonne-kilometer were estimated. Data for intensity for barges, rail, trucking and air freight were taken from the Transportation Energy Data Book. A key assumption is that fossil freight haulage occurs largely at the same energy intensities as other freight. This may be inaccurate for two reasons. First, most fuel haulage is by long distance, often unit trains of only coal or oil or dedicated tanker trucks barges or tankers. These would have low energy intensities because of the scale. However, they have to return largely empty, particularly when liquid fuels are hauled, to avoid mixing fuels of differing types. Thus the use of average energy intensities by mode is only a first approximation.

Each mode of transportation was assumed to use one fuel (except for rail before 1979, which used both diesel and coal). All trucks were assumed to use diesel, all domestic shipping was assumed to use bunker fuel, oil pipelines were assumed to use electricity, and natural gas pipelines were assumed to use natural gas. Rail was assumed to use diesel. Using standard CO₂ coefficients with 100-year global warming potential values, these fuel consumption data for diesel and natural gas combustion are converted into CO₂-eq emissions (including CO₂, N₂O, CH₄, and HFCs, 100 year values) using 2007 emissions factors from the US EPA Inventory of Greenhouse Gas Emissions. Natural gas leakages from pipelines and storage were added to the CO₂-eq emissions count as methane. The electricity used for oil pipelines was converted to CO₂-eq emissions per kWh delivered at US average fuel mix for the year in question, as documented in the AER.

Each of these data sets yielded uncertainty, either from the methods used by others to build the set, or by missing pieces that had to be filled in through projection. Because data sets rarely reported spreads or incompleteness, and where they did report, the format and methods differed, overall uncertainty for calculations in this paper were not calculated.

It is also important to note that these estimates include fossil fuel moved only within the country. Therefore, the movement of oil from the field to a refinery in Saudi Arabia, and then from that refinery across the sea to a U.S. port is not captured (the movement of that oil from the port to the end destination is captured). Expanding the data set to include movements outside the U.S. is an important future project to understand the full upstream costs of using fossil fuel.

Next, a simple decomposition analysis was performed. For a discussion of more complex decomposition analyses, please see the author’s previous paper. This work is carried out in S.I. units.

**PRELIMINARY RESULTS**: FOSSIL FREIGHT WAS RESPONSIBLE FOR ~1.5% OF US ENERGY USE AND ~3% OF CO₂-EQ EMISSIONS IN 2007

Tonne-km of fossil fuel shipped by mode are shown in Figure 6. The share of fossil freight in total domestic freight (including NG and oil) was 35% in 1980 and 32% in 2007. Note: All data for total fossil freight was taken from BTS NTS. For years 1980 and later, BTS has improved statistics for freight that tend to increase the total tonne-km. Therefore, the decrease in fossil freight as percent of total freight reflects this change in data interpretation.
Tonnes have increased more than kilometers, as shown in Table 1. The authors hypothesize that this is because of the increase in imported fossil fuels: points of entry—such as ports—are closer to end-users than traditional extraction locations. However, this hypothesis requires more testing.

Fossil freight energy use remained constant since 1970, using $1.7 \times 10^{12}$ MJ of energy in 2007, compared $1.5 \times 10^{12}$ MJ in 1970. As both transportation and total U.S. energy use increased over this time period, fossil freight as a percent share of total energy use went from 2.1% to 1.5%, as a percent total transportation energy use it went from 8% to 5% (assuming transportation energy totals include pipelines).

**International movements of Fossil Freight not included in this analysis**

These calculations exclude at shipping of imported oil, coal and LNG or CNG to US harbors. In terms of tonne-km this is a serious omission. While full estimates of this figure are not feasible at this time, a few back-of-the-envelope calculations illustrate the magnitude of these additional emissions:

- Canada, the U.S.’s largest oil import partner, sends about nearly 2M bbl/day of its domestic oil production to the U.S. This accounted for about half the total consumed and exported oil in Canada in 2007. If one assumes that therefore, U.S. exports are also responsible for half of the tonne-miles and energy use in oil pipelines in Canada, then an additional 62 billion tonne-km should be added to the U.S. fossil freight bill, increasing oil pipeline tonne-km by 11%.

- 12% of international maritime fuel was consumed by transporting crude oil in 2007. The US consumers one quarter of global oil, and about 40% of U.S. oil comes from countries besides Canada (and thus, are presumed to send oil overseas). Thus, a rough estimate indicates that
including maritime fuel for imports could add it would add $1.7 \times 10^{11}$ MJ to the U.S. fossil freight bill, or 10% on top of the total freight energy cited above.

Shipping oil via tanker is far more efficient than any other mode: therefore, it is possible that importing fossil freight in exchange for reduced ton-mileage domestically (in pipelines) may have reduced overall energy use from fossil freight, even though the distances involved are up to an order of magnitude farther. Note too that both dedicated rail cars and tankers return empty.

As shown in Figure 7, natural gas and oil movements in pipelines dominate fossil freight energy consumption, due to high energy intensity and mileage of pipelines and the preponderance of short-haul trucking in the oil sector (most gas stations, for example, are serviced by trucks that pick up gasoline a several miles away at a depot connected to a pipeline).

As shown in Figure 1, the amount of energy used in freight has been changing much more slowly than all other transportation categories, as well as total U.S. energy use. The reasons behind this are explored in the Laspeyres analysis section.

**Figure 7: Total Fossil Freight Energy by Mode and Fossil Fuel Shipped, 1970-2007.**

- Fossil freight created ~210 MT CO$_2$-eq emissions in 2007, down from 250 MT CO$_2$-eq in 1970. This moves from 4% to 3% of all US emissions, including leakage from natural gas pipelines.

**Figure 8: Grams CO2-eq from fossil freight, by mode and fossil fuel shipped, 1970-2007.**
Fossil freight intensity has gone from 0.7 MJ/tonne-km in 1970 to 0.6 MJ/tonne-km in 2007. The average intensity for all freight was ~3.8 MJ/tonne-km, over six-fold greater than fossil freight. This is due to fossil freight’s low reliance on trucking and aviation, and high reliance on trains and pipelines. However, truck use (or data collected about truck use) has increased ten times over since 1970, a trend that could be tempering fossil freight’s efficiency.

**Why and how did energy use and greenhouse gas emissions change? Laspeyres Analysis**

The following table shows a Laspeyres index for several potential drivers behind the fossil freight energy tab for the years 1970, 1980, 1990, 2000, and 2007. The table shows that different factors are balancing to create the slight decrease energy use in fossil freight. Between 1970 and 2007, whereas tonnage (a close proxy for total U.S. fossil fuel use) more than doubled, the average trip distance nearly halved, leading to only a slight increase in tonne-km. This decrease is driven largely by a ~75% decrease in reported average domestic trip distance for oil (within US borders, not on sea or Canadian pipeline); coal average trip length remained relatively constant, and natural gas reported average distance dipped in the mid 1980s, then returned to 1970s levels. Then, a reduction in energy intensity per tonne-km compensated for the remaining increase in tonne-km. Energy intensity also went down, balancing an increase in tonne-km.

**Table 1: Indices of Variables in Energy Use for Fossil Freight for five selected years. 1990 = 100%**

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<tbody>
<tr>
<td>Energy Use</td>
<td>97%</td>
<td>95%</td>
<td>100%</td>
<td>101%</td>
<td>107%</td>
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Table 2: Laspeyres Index of Fossil Freight 1970-1990 with 1990 = 100%

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<tr>
<td>Actual emissions</td>
<td>114%</td>
<td>110%</td>
<td>100%</td>
<td>97%</td>
<td>95%</td>
<td>-19%</td>
</tr>
<tr>
<td>Activity (tkm)</td>
<td>100%</td>
<td>99%</td>
<td>100%</td>
<td>117%</td>
<td>118%</td>
<td>18%</td>
</tr>
<tr>
<td>Mode shift</td>
<td>98%</td>
<td>101%</td>
<td>100%</td>
<td>95%</td>
<td>99%</td>
<td>1%</td>
</tr>
<tr>
<td>Carbon intensity</td>
<td>115%</td>
<td>111%</td>
<td>100%</td>
<td>87%</td>
<td>82%</td>
<td>-33%</td>
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<tr>
<td>Fuel Mix</td>
<td>106%</td>
<td>110%</td>
<td>100%</td>
<td>98%</td>
<td>96%</td>
<td>-10%</td>
</tr>
<tr>
<td>Fuel Intensity</td>
<td>124%</td>
<td>103%</td>
<td>100%</td>
<td>87%</td>
<td>83%</td>
<td>-41%</td>
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As Table 2 shows, a reduction in carbon intensity of the energy used to move fossil fuel and the intensity of the fuels used are the largest drivers behind the decrease in greenhouse gas emissions from fossil freight. Improvements in the carbon intensity of electricity, reductions in the fuel intensity of trucks, barges, and trains, and reduction in leakages from natural gas pipelines all contribute to these trends.

Including pipelines: important for policy makers

If included in analyses of freight, pipelines would significantly change the energy and carbon impact of the freight sector. The following table shows the impact of including pipelines in a freight analysis.

Table 3: Key indices without pipeline data.

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<tbody>
<tr>
<td>Energy Use</td>
<td>73%</td>
<td>86%</td>
<td>100%</td>
<td>110%</td>
<td>137%</td>
</tr>
<tr>
<td>Intensity (MJ/tonne-km)</td>
<td>94%</td>
<td>97%</td>
<td>100%</td>
<td>86%</td>
<td>101%</td>
</tr>
<tr>
<td>Tonne-km</td>
<td>89%</td>
<td>84%</td>
<td>100%</td>
<td>128%</td>
<td>136%</td>
</tr>
<tr>
<td>Average Trip Distance</td>
<td>113%</td>
<td>100%</td>
<td>100%</td>
<td>126%</td>
<td>56%</td>
</tr>
<tr>
<td>Tonnage</td>
<td>50%</td>
<td>74%</td>
<td>100%</td>
<td>123%</td>
<td>171%</td>
</tr>
</tbody>
</table>

Table 3 implies that exclusion of pipeline data masks the trends noted above: energy use appears to have gone down more rapidly, as does intensity. Tonne-km appear to have gone up less rapidly because the baseline in 1970 (or any year) is larger. Table 3 shows, for each category as well as carbon dioxide equivalent emissions, pipeline-only data as a percent of the sum of non-pipeline data.

Table 4: Pipeline contribution as percent of non-pipeline sum for each key category.

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<tbody>
<tr>
<td>Energy use</td>
<td>31%</td>
<td>20%</td>
<td>16%</td>
<td>12%</td>
<td>11%</td>
</tr>
<tr>
<td>Tonne-km</td>
<td>53%</td>
<td>37%</td>
<td>31%</td>
<td>28%</td>
<td>24%</td>
</tr>
<tr>
<td>Tonnage</td>
<td>125%</td>
<td>91%</td>
<td>73%</td>
<td>66%</td>
<td>49%</td>
</tr>
<tr>
<td>CO2-eq emissions</td>
<td>43%</td>
<td>29%</td>
<td>21%</td>
<td>14%</td>
<td>13%</td>
</tr>
</tbody>
</table>

Table 4 indicates that by ignoring the contributions of pipelines, policy makers seeking to understand and address freight could be missing up to half of domestic freight tonnage, under-attributing CO2-eq
emissions as well as energy use and tonne-emissions to the freight sector. Pipelines are shrinking relative to energy use, tonnage, etc for all fossil freight because of the rise of trucking for oil, and increase in coal use.

Figure 9: Total fossil tonnage consumed in U.S., 1970-2007.

Figure 10: Imports as percent of total oil use in the U.S. compared to average trip length for oil indexed to 1970, 1970-2007

Trip length

Trip length was calculated in different ways for different fuels, depending on data availability. For coal data, average trip length for each mode was calculated using the CTRDB (see Method section, above). For oil and natural gas, average trip length was taken from diving tonne-km by tonnes shipped.

It is impossible to discern, from these data, why the average trip length for oil decreased so significantly, while trip length for coal remained relatively constant and natural gas length dipped in the mid 1980’s and then returned to 1970’s levels. One hypothesis is that decreasing average trip length coincides with an increase in oil imports, shown in Figure 10. If the distance between oil intake ports locations and locations where pipelines cross from Canada (the U.S.’s primary import partner) are closer to oil use centers than traditional domestic oil production locations, it could partially or fully account for the decreasing trip length trend. The trend for imports as percent of total consumption and average trip length are almost exactly inversely proportional, indicating that integrating the out-of-country transportation will be an important theme for future research. The importance of capturing out-of-country or “spilled” emissions from manufacture and freight of for all consumed goods has been pointed out recently, and named consumption-based accounting. Capturing global fossil freight emissions from fossil fuels used in the U.S. will require significant additional research, and may be hindered by even more challenges relating to historical data availability.
CONCLUSIONS AND IMPLICATIONS FOR POLICY AND FUTURE RESEARCH

Fossil freight contributes significantly to U.S. freight haulage, energy use and greenhouse gas emissions. Reducing use in fossil fuel use through improved efficiency will have compound benefits in reducing fossil freight energy and emissions. However, when fossil fuel use reductions are achieved through substitution of other fuels, care must be taken to avoid "hidden" increases in fossil freight energy use and emissions. The average intensity of non-fuel freight per tonne-km is almost four times as high as fossil freight. Therefore, care should be taken to structure any policy pushing towards replacement fuels that require transport (such as biomass and biofuels and an increase in natural gas for electricity production over coal) so as to resemble the fossil freight infrastructure, as opposed to the standard freight infrastructure. Ethanol, for example, is often transported in trucks instead of pipelines, adding to its freight bill. In addition, it is critical for researchers and policy makers to include the impacts (transportation and otherwise) emerging from the processing of fuels abroad, before and while they are imported into U.S. boundaries. This will require new approaches to data collection.

Making good on such an attentive policy program requires several additional activities: better availability (digitization in usable format) of historical records, better and more transparent record keeping of major freight and fuel movements going forward, inclusion of pipelines as part of freight, and using figures fully burdened with "up-stream" energy and greenhouse gas costs (including transportation) when calculating the impacts of any new energy policy. Our work reconciles diverse sources of varying quality, particularly before 1980. Our reach far back to 1970, however, permits at least a cursory view of trends just as the first oil crisis occurred and there after.

The prospect of a reduction in fossil freight opens up an intriguing long term policy questions. Fossil freight in 2007 was responsible for 100% of pipeline usage, 40% of freight rail tonne-km, and 15% of domestic waterborne tonne-km. These three modes are an order of magnitude (or more) less energy intensive than trucking, and drastically more efficient than air freight. As the nation reduces fossil fuel use and frees up this efficient freight infrastructure, can leaders construct policies and plan infrastructure to

![Graph showing exponential trends](image-url)
utilize this capacity for non-fossil freight, and, in doing so, tackle the ever-increasing intensity and
greenhouse gas emissions from the larger freight industry? Will fewer shipments of oil and coal by rail
allow faster shipments of other goods by rail rather than truck? Answering such a question requires
extensive conversation and integration between engineers, policy makers, and business leaders.

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